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Modeling Dynamic Casualty Mortality Curves in the Tactical Medical Logistics (TML+) Planning Tool

R. Mitchell
M. Galarneau
B. Hancock
D. Lowe

Report No. 04-31

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NAVAL HEALTH RESEARCH CENTER
P. O. BOX 85122
SAN DIEGO, CA 92186-5122

BUREAU OF MEDICINE AND SURGERY (M2)
2300 E ST. NW
WASHINGTON , DC 20372-5300

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Ray Mitchell, Ph.D.
Teledyne Brown Engineering
300 Sparkman Drive
Huntsville, AL 35805

Mike Galarneau, MS NR EMT-D
Naval Health Research Center
P.O. Box 85122
San Diego, CA 92182-5122

Bill Hancock
MTS Technologies, Inc.
2800 Shirlington Road, Suite 1000
Arlington, VA 22206

Doug Lowe
Teledyne Brown Engineering
300 Sparkman Drive
Huntsville, AL 35805

Technical Report No. 04-31 was conducted under Work Unit 63706N M0095.005-60320. The views expressed in this article are those of the authors and do not reflect the official policy or position of the Department of the Navy, Department of Defense, or the U.S. Government. Approved for public release; distribution unlimited. This research has been conducted in compliance with all applicable federal regulations governing the protection of human subjects in research.

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Abstract

Medical simulation models such as NHRC's Tactical Medical Logistics (TML+) planning tool stochastically represent the mortality of casualties with life-threatening injuries at various time points in the Medical Treatment Facility (MTF) network flow. This paper describes how NHRC is seeking to determine a mathematical (probabilistic) representation of a conditional survival function that is reasonable in the context of other, rather simple, stochastic models being used in TML+. The paper describes NHRC's overall research approach to determine an acceptable TML+ model for the mortality function, describes subject matter expert (SME) opinion results being used as the basis for an interim descriptive model using a biomedical sciences probability model (Weibull), and gives the future plans to capture more quantitative mortality and treatment data from the Navy-Marine Corps Combat Trauma Registry and other sources to use in investigating the applicability of a full range of biomedical sciences probability models via inferential methods.

Introduction

TML+ is a C++ open-architecture software program designed for Navy and Marine Corp medical planners as a simulation tool that models the flow of patients from the point of injury (POI) through more definitive care; more generally, it is an operations research tool that supports systems analysis, risk assessment, and field medical services planning [8]. Figure 1 is the network view of an illustrative medical treatment facility (MTF) consisting of a 1st Responder, a Battalion Aid Station (BAS) and a Casualty Receiving and Treatment Ship (CRTS) connected by transportation assets. The figure also shows our assumption about how improving medical capability in the MTF stream mitigates the death rate across time.

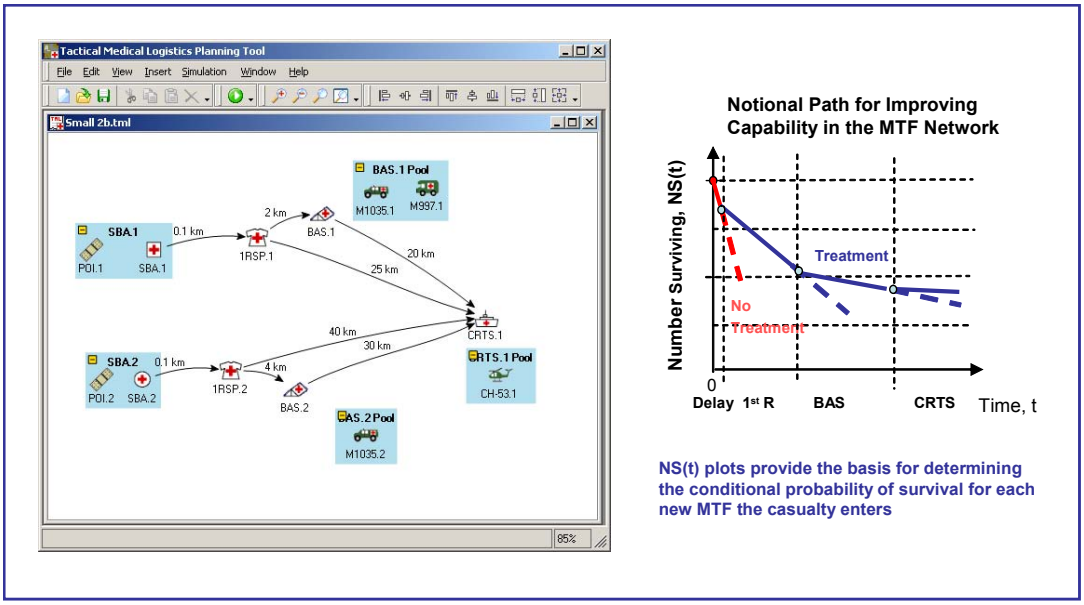


Figure 1 - Illustrative MTF network and its associated improving medical interventions.

The patient flow process can be viewed as a network of stochastic queuing processes, as Figure 2 shows. These processes generally involve random outcomes associated with patient arrivals, injury conditions, mortality events, treatment times and transportation loading/timing events.

As mortality modeling is the subject of this paper, a brief introduction to how TML+ simulates these events is given next; the TML+ methodology manual describes the entire process [8].

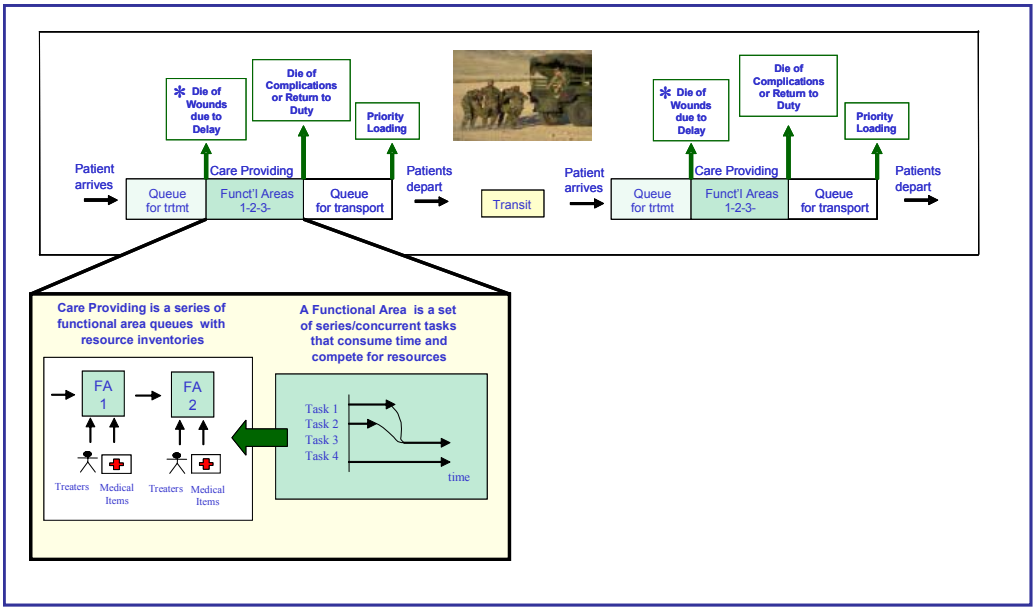


Figure 2 - TML+ as a network of stochastic queues.

TML+ models mortality as killed in action, died of wounds due to complications (DOC), and died of wounds (DOW) due to a delay in treatment (the latter two events are depicted in Figure 2). Generally, the Bernoulli random variable [9] as shown on the left side of Figure 3 is used to simulate a mortality event for all three categories. For the KIA and DOC events, the probabilities used in the Bernoulli simulation are static and do not vary over time. The KIA events are simulated from a constant probability that is used for each newly generated casualty.

The DOC events are simulated from a set of probabilities that depend on the patient condition (PC) and the level of care (LOC) functional area, but are not time dependent. The DOC event is simulated after each functional area, given disposition probabilities contained in the Estimating Supplies Program (ESP) [8] task sequence profile for the associated patient condition.

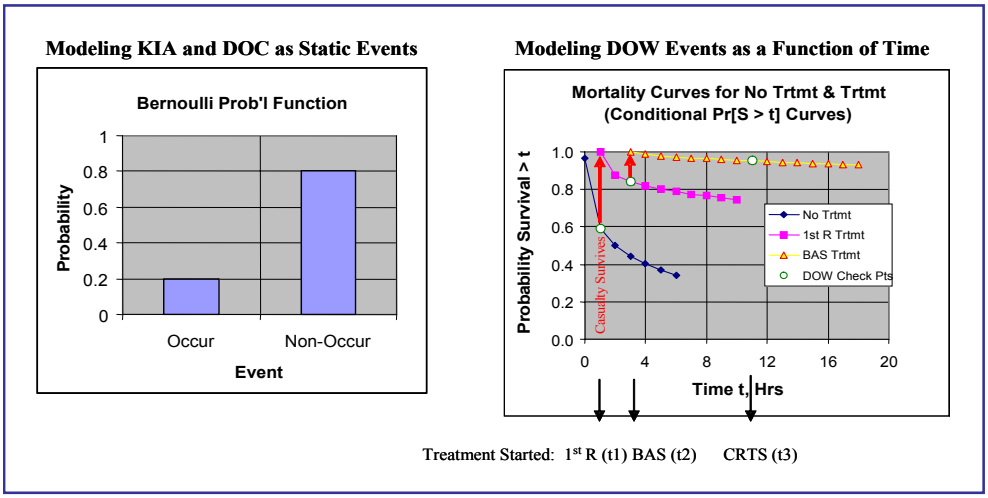


Figure 3 - Simulating mortality in TML+.

In simulating the DOW events, the right side of Figure 3 shows how TML+ models the degradation in survival probability (1-probability (DOW)) for a delay in treatment, and the improvement in survival chances for successive and more capable medical interventions in the treatment stream. It is emphasized that these hypothetical curves, when evaluated at any time "t", give the probability of survival past that time, and are conditional on the casualty surviving to have entered the associated LOC.

For example, if the time simulated to receive treatment at the 1st Responder LOC is time t1, the model uses a probability of approximately 0.60 (from the figure) in a Bernoulli draw to determine if the casualty survives past this time or not. On the graph for "No Treatment", t1 is labeled a "DOW Check Point". For DOW testing, no treatment is assumed to occur before the 1st Responder LOC and all casualties with a life-threatening condition degrade from the time-of-injury on the "No Trtmt" curve applicable to their PC. If the casualty does not survive, the casualty is labeled a DOW and is dropped from the simulation; if the patient survives, he enters treatment at the 1st Responder (i.e., is alive with probability 1.0 at t1) and is now assumed to receive continuous treatment there with a different set of conditional probabilities, determined by the curve labeled "1st R Trtmt" in the graph. As the patient progresses through the MTF network, simulation of the DOW (probability of survival) event is repeated until the patient no longer survives, is returned-to-duty or is evacuated out of theater.

The subject of this paper is to describe how NHRC is seeking to determine a mathematical (probabilistic) representation of that conditional survival function in Figure 3 which is reasonable in the context of the other, rather simple, stochastic models being used in TML+. The remainder of the paper is organized as follows: section two describes NHRC's overall research approach to determine an acceptable TML+ model for the mortality function, section three describes subject matter expert (SME) opinion results being used as the basis for an interim model, section four describes how a biomedical sciences probability model (Weibull) is being used with the SME results in an initial implementation, and section five gives the future plans to capture more quantitative mortality and treatment data from the Navy-Marine Corps Combat Trauma Registry [3] and other sources to use in investigating the applicability of a full range of biomedical sciences probability models.

Research Approach

NHRC's research approach to determining a time-based mortality function for delays in treatment is shown in Figure 4. For a sense of perspective, the far left of the figure shows how early modeling of the mortality function was simply a constant value applied to individual PCs and functional areas, as in the DOC simulation previously described. Bellamy's work [1] illuminated the need for a time-based representation (his "golden-hour") and a study by Hassell, et. al., [6] shows an intuitive, so-called saw-tooth model that was first implemented in an earlier version of TML+. The remaining blocks show NHRC initiatives to derive a stochastic model to embed in TML+ based on expert opinion and actual treatment/mortality data.

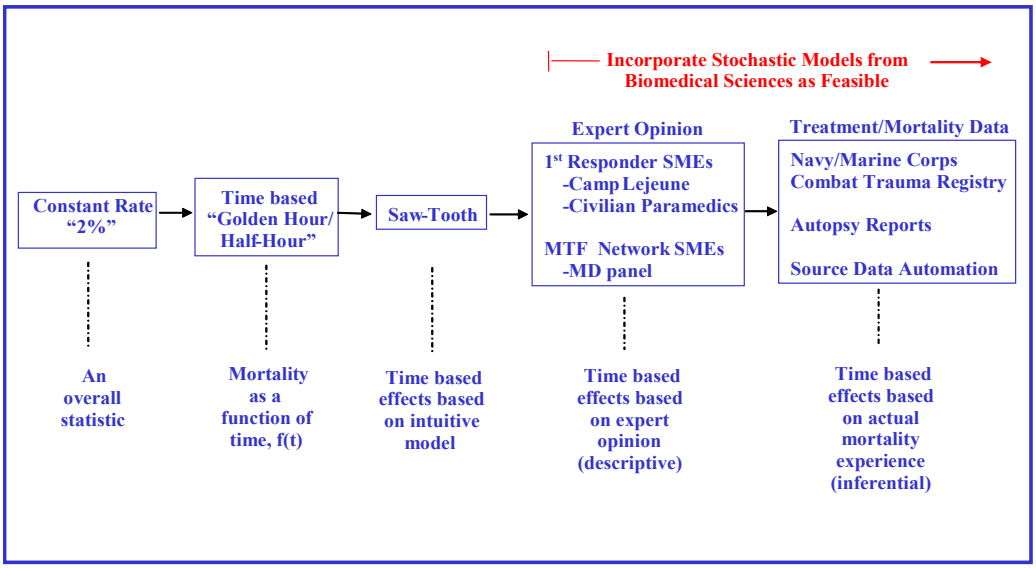


Figure 4 - Evolution of NHRC's research approach to determining treatment delay mortality function. Timeline – early work through present implementation.

Several efforts to collect applicable expert opinion results on mortality have been conducted by NHRC. In 2002 and 2003, a group of 1st responders at Camp Lejeune and a group of civilian paramedics in Northern Virginia were polled on a select group of urban patient injury codes in order to help perfect a questionnaire approach and gain insight into the nature of the probability of survival function for delays in providing first treatment to a casualty. In November 2003, a group of military medical providers who were experienced in MTF network care for combat casualties (many had been deployed with Operation Iraqi Freedom) participated in an effort to collect opinions on treatment effects versus delays that might be experienced for the entire theater casualty stream. This effort will be presented in the next section, as these results are the descriptive basis for our initial stochastic algorithm for the DOW function in TML+.

The last block in Figure 4 shows the overall research goal, that of forming a stochastic model that is statistically reasonable in the context of actual treatment and mortality data. NHRC is developing the Navy-Marine Corps Combat Trauma Registry that will allow data to be analyzed on all combat casualties at any point in the casualty flow. Mortality data from the Armed Forces Institute of Pathology are also expected to be available for analysis. It is hoped that future efforts to collect real-time mortality and treatment data on the battlefield will take advantage of source data automation (SDA) techniques such as "pervasive computing".

Complementing the SME opinion results which are being used to identify reasonable mortality models, the use of actual treatment/mortality data from the Navy-Marine Corps Combat Trauma Registry and other sources will permit NHRC to conduct a more rigorous inferential analysis. The overall objective of the latter two blocks in the figure is to

leverage the analysis of lifetime data via stochastic modeling that has been conducted over many years in the biomedical sciences discipline [2, 4, 5, 9]. An introduction to a few of the applicable functions and to one of the stochastic models is provided next.

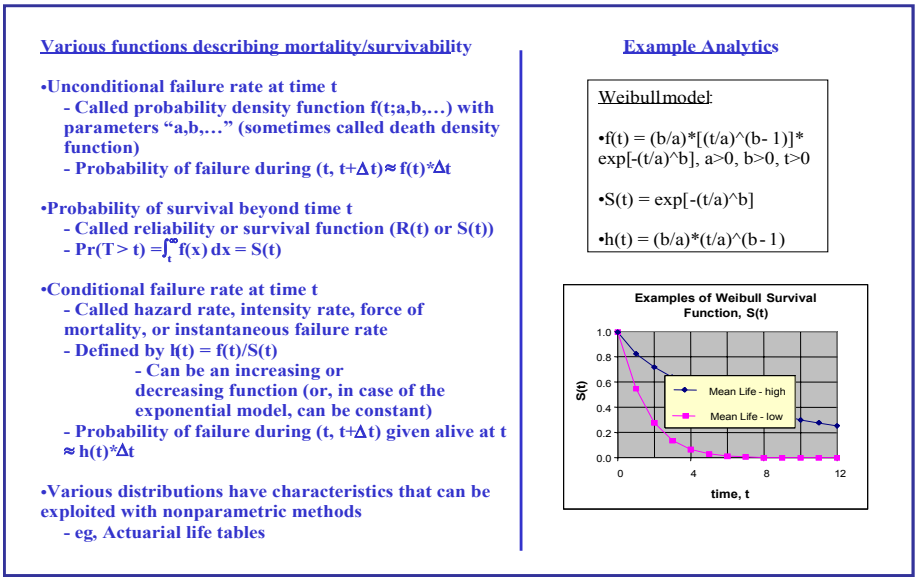


Figure 5 - Tentative probability models and functions from the Biomedical Sciences.

Figure 5 shows the functions that have proven to be effective in describing human lifetimes in the biomedical sciences field. These results have been shown to apply to the effects of treating cancer patients and other life-threatening illnesses where a medical treatment intervened (or stages of treatment); we acknowledge that these types of medical conditions are not like combat injuries, but it is expected that the stochastic lifetime properties might be similar enough to consider the biomedical sciences models as tentative descriptive candidates. On the left of the figure we show the probability density function of lifetimes with parameters {a, b,...}, the survival function for the probability of survival past time "t", and the conditional failure rate or force of mortality function at time "t". Various probability density functions that have been shown to apply in biomedical sciences are the gamma, Weibull and Gompertz models. The three functions for the Weibull distribution are shown on the right of the figure, along with the graph of its survival function. The 1st Responder results and the SME MD panel results, to be presented later, have this same general shape.

In an initial attempt to describe the SME MD panel opinion results, we will use the Weibull model until more quantitative data are available for consideration via the Navy-Marine Corps Combat Trauma Registry and other sources. The next section describes the SME medical provider panel results.

Military Medical Provider SME Panel as an Interim Source of Mortality Estimates

In this section, we will give an overview of the methods used to collect opinion results from a group of military medical providers who convened at NHRC in November 2003. We will also summarize these results.

Figure 6 shows that 12 medical providers (the SME panel, the composition of which appears in Appendix A) were asked to collect mortality estimates, given selected life-threatening PCs with initial signs and symptoms, at given LOCs, and with specified delays in treatment. The panel was given an evacuation scenario involving a hypothetical group of 100 casualties at an initial Point of Injury (with given PCs, signs, and symptoms) for which they were to estimate the number of survivors as time elapsed. The SMEs completed data arrays, such as the ones shown, using wireless personal data assistants (PDAs) and instant polling software. (An interesting article about "human behavior and how we decide what's risky" [1], coupled with our intuition that this metric would be less ambiguous than a probability of surviving quantity, was our rationale for polling the panel on "number surviving"). Example data results will be given next.

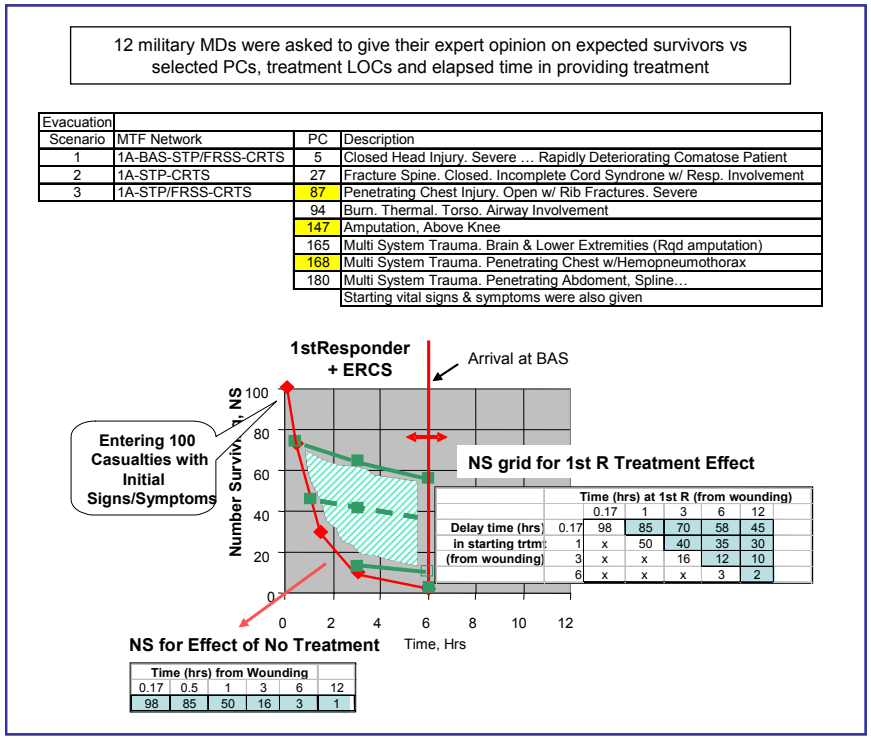


Figure 6 - Overview of process used to collect SME responses to estimate the Mortality Function.

For the effects of no treatment for a particular PC, each provider estimated how many of the 100 casualties would still be alive at 10 minutes, 30 minutes, 1 hr, …, 12 hrs prior to receiving any attention by a 1st Responder (sample inputs are shown in blue in the bottom left array). Similarly, the right most array shows how their responses were collected

[1] Achenback, J. "Who Knew?", *National Geographic*, September 2003.

for various delays in starting 1st Responder treatment (inputs in blue; the diagonal entries were transferred from the first array).

To illustrate the data, the responses for a 1 hour delay indicate that an SME estimated that if continuous treatment did not start until 1 hour after wounding, 50 casualties would have survived to that time, and 40 would be surviving at 3 hours, versus 16, if there had been no intervening treatment for 3 hours. The graph shows a typical plot that resulted when all 12 SME responses were combined (in a manner to be explained later). In TML+ we need to describe the totality of points that might result, given various combinations of simulated treatment delays at the 1st Responder and subsequent arrival times at the next LOC (here, a BAS). We call this area the 1st Responder treatment effect feasible region; it includes treatment time at the 1st Responder and the time associated with care given by the en-route-care system (ERCS) before the patient enters treatment at the BAS. An ensemble of delays and treatment times were presented to the SMEs for each PC, allowing for an estimate of the Number Surviving response for any point in the feasible region.

As given in Figure 6, eight PCs were used to solicit responses from the SME panel, and for each of the indicated scenarios. The matrix shows a brief description of each PC; initial vital signs and symptoms were also given to the panel. The three highlighted PCs are ones that will be used to illustrate the overall nature of the responses in the material to follow.

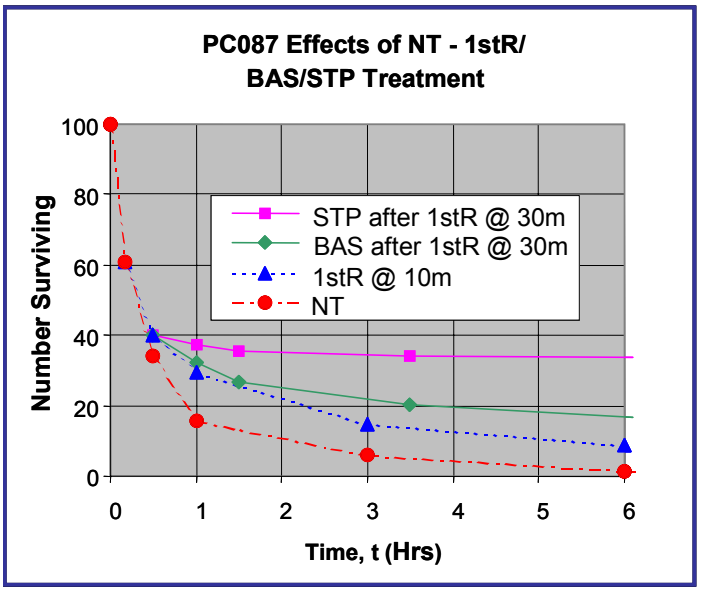


Figure 7 - Sample results.

As an introductory plot displaying the nature of the responses, Figure 7 shows the estimated results for PC087 (severe thorax wound, open chest injury with rib fractures) for the 1st Responder's treatment effect, coupled with the effects of STP and BAS alternatives after the 1st Responder. The treatment delay for the 1st Responder is taken to be 10 minutes; for the alternatives, we assumed the casualty entered treatment at either the STP or BAS 30 minutes

after injury. This plot illustrates the nature of increasing medical care at successive levels in the MTF network, and also shows that, of the two destinations to which to evacuate from the 1st Responder, the STP is more effective than the BAS for this PC.

The next section shows some of the individual responses and how we aggregate the results to more easily describe some initial notions about the stochastic nature of the mortality function being sought for TML+. (Again, our long term goal is to be able to statistically analyze actual mortality data from the Navy-Marine Corps Combat Trauma Registry and other sources).

Individual Results, Smoothing Approach and Mortality Risk Categories

This section will show some of the individual panel member plots and how we combined (smoothed) these results into a single descriptive response. We will also display the smoothed results for the effects of no treatment across all eight PCs and show how we chose to collapse the set into three so-called mortality risk categories for an initial implementation.

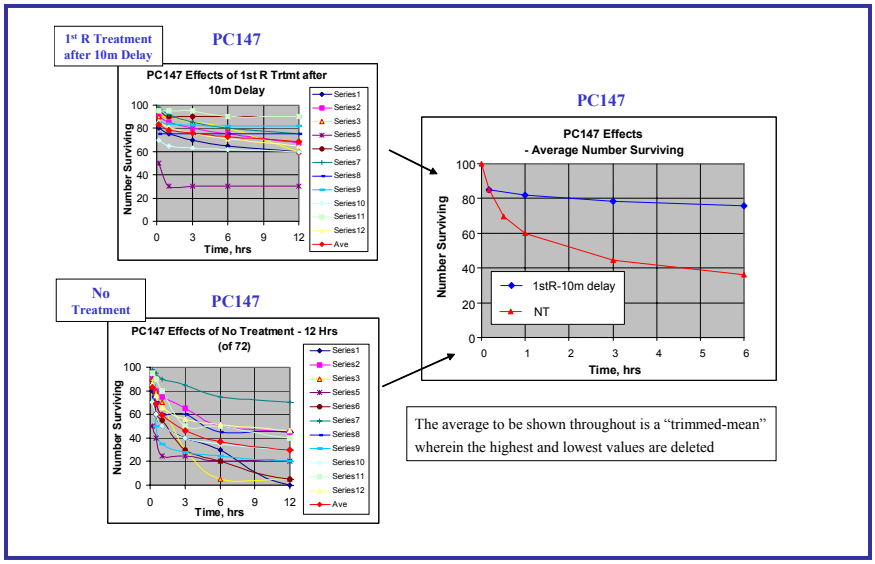


Figure 8 - Individual results for PC147 and smoothing approach.

Figure 8 shows the panel members' individual responses for PC147 (complete above knee amputation) for the "no treatment" case and for the "1st Responder treatment effect after a 10 minute delay" case. Except for a very few high and low values, the individual plots appear to be fairly consistent in their overall trends. Since our objective with these results is to get an idea of the general descriptive nature of the mortality function suitable for a first

implementation in TML+, we choose to thin the results by trimming the highest and lowest value at each time point polled, then average the remaining estimates. The "Ave" curve in each plot shows this trimmed mean; the two curves are plotted together on the right side of the figure, and the nature of the trends in both cases is readily visible.

It is clear that quick treatment by a 1st Responder is expected to almost totally mitigate the life-threatening conditions represented by this PC. For example, of an average 82 survivors at 10 minutes, about 95% survive past three hours, versus only about 50% if there is no treatment. Next we show the (average) number surviving plots for all eight PCs.

The left side of Figure 9 shows, for estimates of the effect of no treatment, the trimmed-mean values for all eight PCs. We see that they range from a gradual decay in mortality for PC168 (MIW chest and abdomen wound, perforated bladder) to a rapid degradation for PC087. It is these curves we seek to describe with an initial probability model (and like curves for the other MTFs in various evacuation scenarios). Indeed, for the present, we would be pleased to be able to represent the boundaries of the region shown as well as a mid-range case. To this end, we next define so-called high, medium and low mortality risk categories.

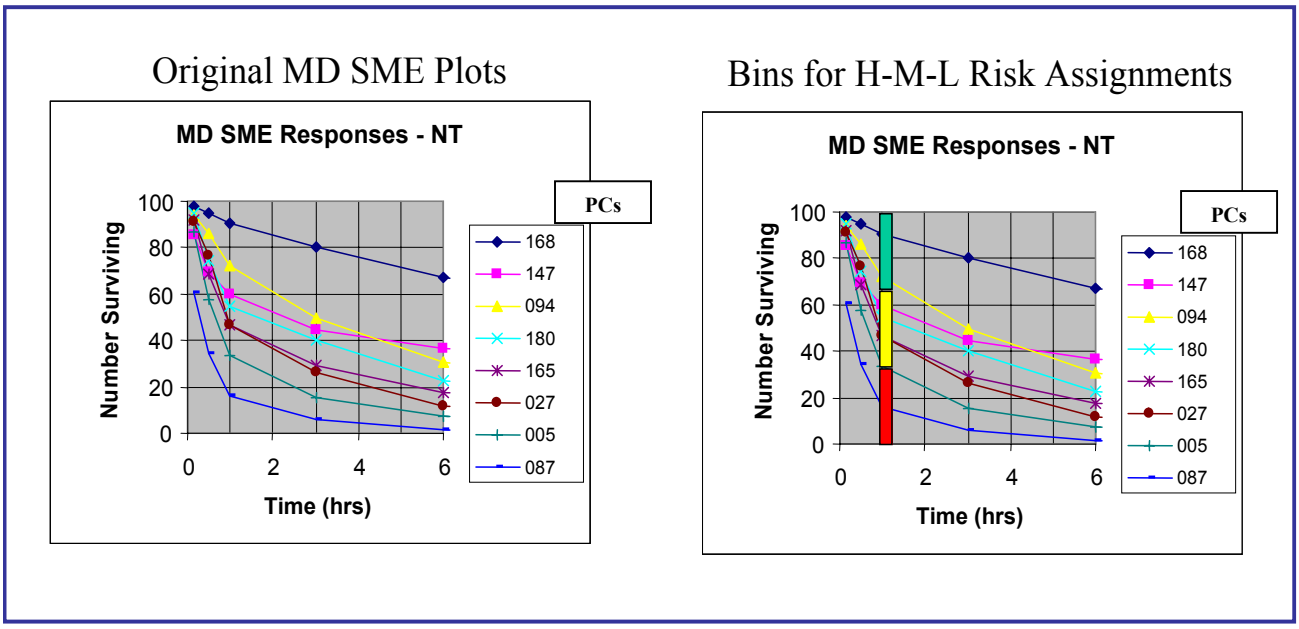


Figure 9 - No Treatment results for all Patient Conditions and mortality categories.

It seems reasonable to divide the life-threatening PCs into risk sets characterized by the probability of surviving past one hour with no treatment as occurring in intervals {0, 0.33}, {0.34, 0.66} and {0.67, 1.0}. This would correspond to the "number surviving" at 1 hour to be between 0 and 33, 34 and 66, etc. in the present context. The right side of Figure 9 shows this characterization superimposed on the number surviving graph of the left figure. We choose to take PC087 to represent the highest mortality category (low probability of surviving past one hour), PC147 to

represent the mid-range, and PC168 to represent the lowest mortality risk. For the present we will concentrate on describing the SME responses for these three PCs and apply results to be developed later to the total group of life-threatening PCs (see Appendix B for table of PCs and mortality risk categories as considered and mapped by SMEs at NHRC).

No Treatment, 1st Responder and Next LOC after 1st Responder Results for H/M/L Mortality Categories

In this section, we show the SME responses for the three mortality risk categories just defined for the cases of "no treatment" and for "1st Responder treatment" effects. We also show effects for the three evacuation alternatives after the 1st Responder.

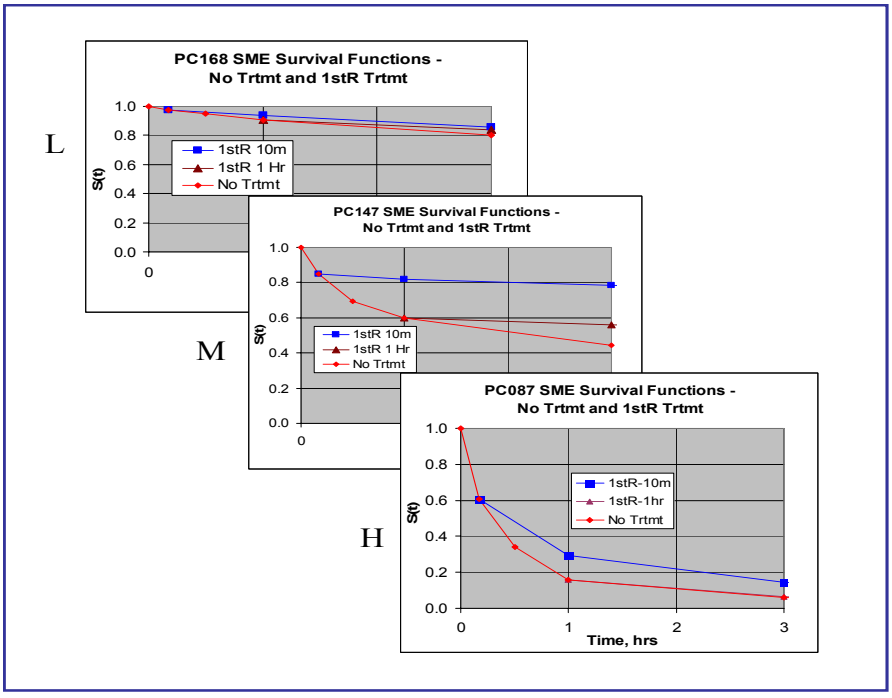


Figure 10 - No treatment and 1st Responder summary SME results by mortality category.

Figure 10 shows the "no treatment" smoothed responses (converted to survival probabilities) for the low, medium and high mortality categories as extracted from Figure 9. They range from a rapid and non-linear degradation for PC087 to a less severe and near linear degradation for PC168. The 1st Responder treatment effects for delays of 10 minutes and one hour are also shown.

It is easy to see that the medium risk PC category is estimated to respond nicely to quick 1st Responder treatment and indeed, delays up to one hour have a visible effect in mitigating the effects of no treatment. The responses for PC087 (high risk mortality) indicate only a slight improvement in the survival function for a short delay while the delay for one hour appears to have no effect. The low mortality case shown suggests that this category of PC has little degradation and would probably not be a candidate for priority treatment by the 1st Responder.

Figure 11 shows responses for the next three evacuation options considered after the 1st Responder. In these plots we show the probability that the casualty survives past one hour, and three hours, if alive when entering the facility three hours after the time of injury. (This "conditional" measure is used in a large sense to decouple the entering LOC response estimates from the specific details of previous LOC interventions.)

The three hours after injury timing is rather arbitrary, as there would be an infinite number of possible times, given the simulation nature of TML+. It is clear from the figure that the BAS is not as effective as the STP or STP/FRSS as the next LOC after the 1st Responder for the high risk PC category.

It is also evident that the STP/FRSS treatment effects are estimated as highly effective in saving survivors from the 1st Responder location. It may also be noted that the STP and STP/FRSS are more effective than the BAS in stabilizing the casualty for the medium and low risk categories (comparing probability of survival > 3 hours to probability of survival > 1 hour). We expect these observations would be the same even if time intervals other than the three hours from POI we used here were chosen.

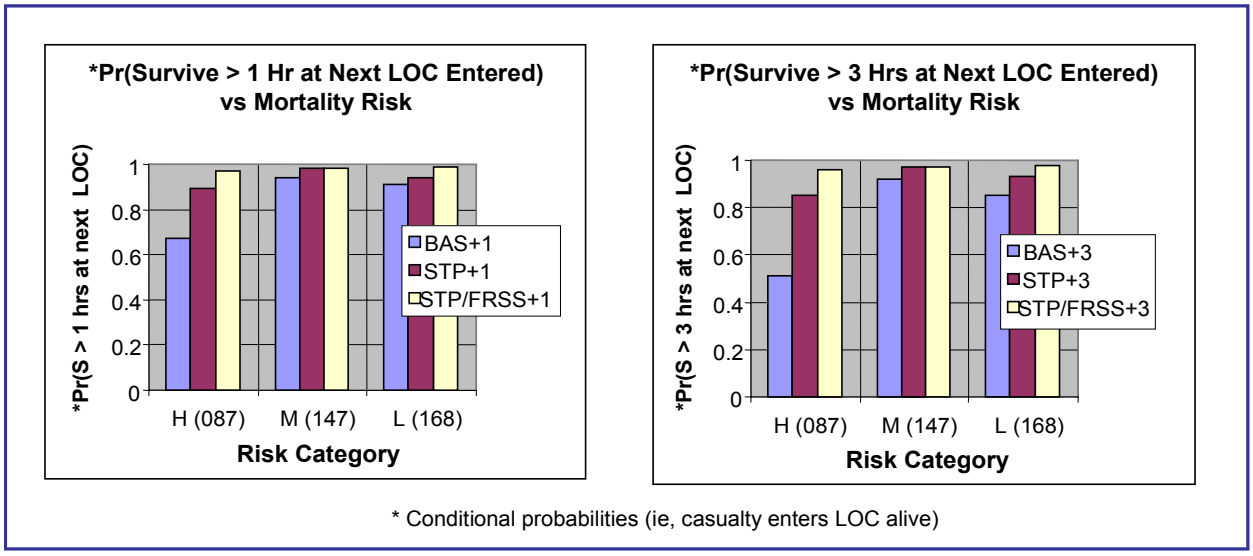


Figure 11 - Conditional probability of survival values at next LOCs after 1st Responder.

Representative Results across all Evacuation Scenarios and Mortality Risk Categories

Referring back to Figure 6, it is easy to see that there is a tremendous amount of response data to help describe the time-based survival function we seek. Our challenge is to depict representative results in a longitudinal manner corresponding to the various evacuation scenarios in an effort to describe a tentative form of the survival function for each of the mortality risk categories.

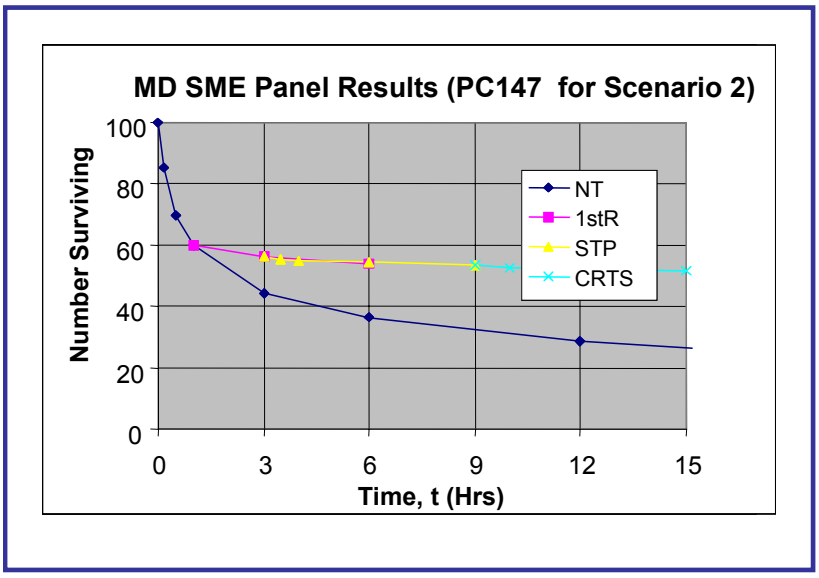


Figure 12 - Number Surviving for evacuation Scenario 2 (for PC147).

Figure 12 shows, for evacuation scenario 2 and PC147, the estimated number of survivors across the several MTFs. In this case, the 1st Responder begins treatment at 1 hour after injury, the STP at 3 hours and the CRTS at 9 hours. Given the grid of treatment delays we chose (see Figure 6), a myriad of graphs would result and our goal is to describe the general nature of the ensemble of responses for our initial implementation in TML+. We expect the functional form to be consistent across the grid where applicable parameters for a particular simulation realization in TML+ can be estimated via an interpolation approach that we expect to implement later.

In Figure 12 we can easily see that the surviving number is expected to be almost constant with time after the first few treatment interventions. That is, the conditional probability of survival with time would be very high--and almost horizontal--given the casualty survives to enter the facility.

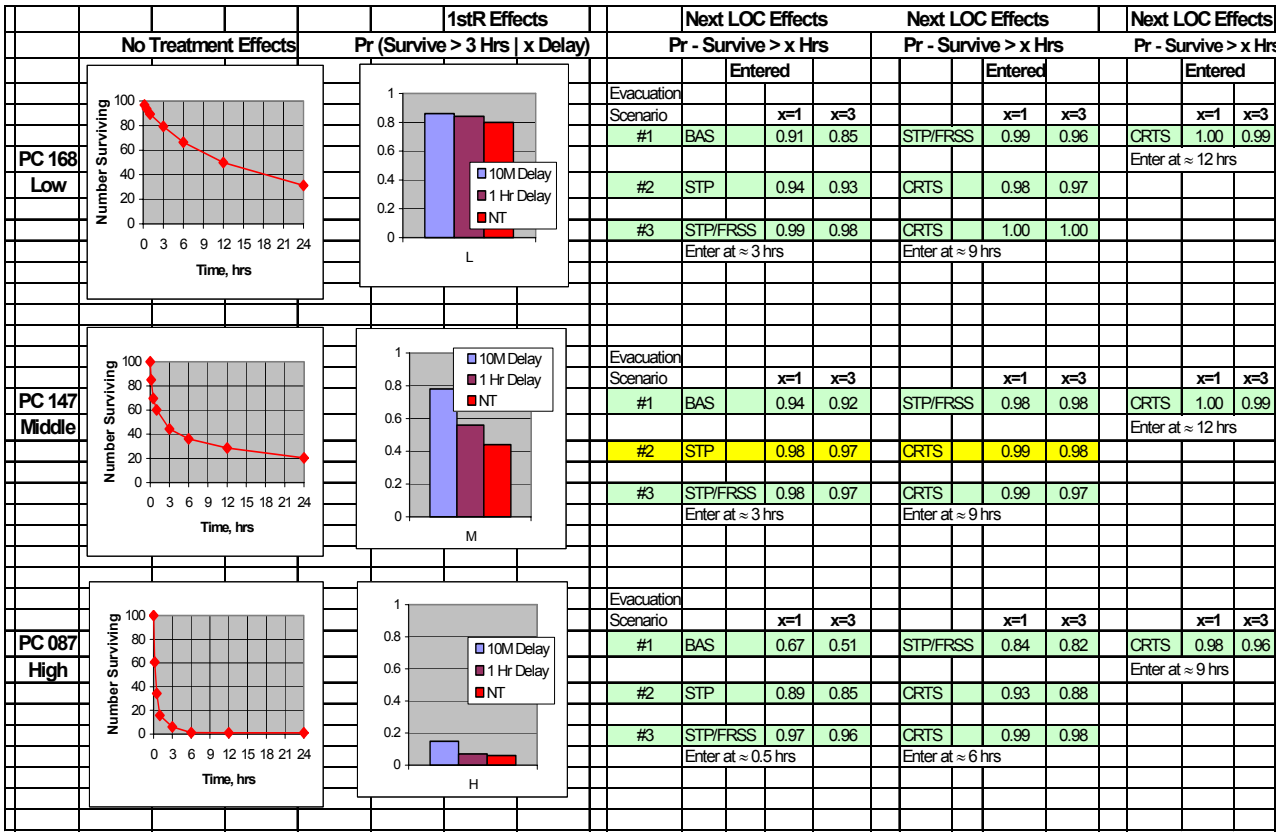


Figure 13 - Summary of representative results for all evacuation scenarios and mortality categories.

In Figure 13 we attempt to summarize representative SME responses across the various evacuation scenarios and the three mortality risk categories. In the far left column of graphs, we repeat the plots of number surviving with no treatment for the three mortality categories (an extension of Figure 10 out to 24 hours).

The next column shows the unconditional probability of surviving past three hours given 10 minute and one hour delays in starting 1st Responder treatment (from Figure 10); it also shows, for comparison purposes, the probability of surviving past three hours without treatment. The next column begins to show the effects of evacuation alternatives after the 1st Responder--here we show the conditional probability of surviving past one and three hours, given the simulation casualty survives to enter the facility (from Figure 11).

The last two columns show similar results for the remaining LOCs in the various evacuation scenarios. For the last three columns illustrated, the assumed timing from injury to entry at the respective LOCs is indicated. These are nominally the lower end of the time grid that was presented to the SME panel for these scenarios; estimates for

longer times were also polled but are not shown here. Estimates from the entire grid are used in describing the survival function where the upper and lower time values will be used to interpolate the results, if deemed necessary.

In the results for the last three columns, we see that the estimates are fairly constant (comparing the entries for "x=1" to "x=3") particularly for the medium and low mortality risk categories. These results suggest that describing the form of the survival function is perhaps more important for the first few treatment interventions shortly after the injury. In all of the SME results we have examined, the survival function appears to be almost linear for the latter medical interventions.

Figure 13 also shows the conditional probability estimates for the survival function depicted in Figure 12 using "number surviving". In the next section, we present how the Weibull survival function from the biomedical sciences discipline is used to describe the SME results given here.

Using a Biomedical Sciences Model to Describe the SME Mortality Estimates

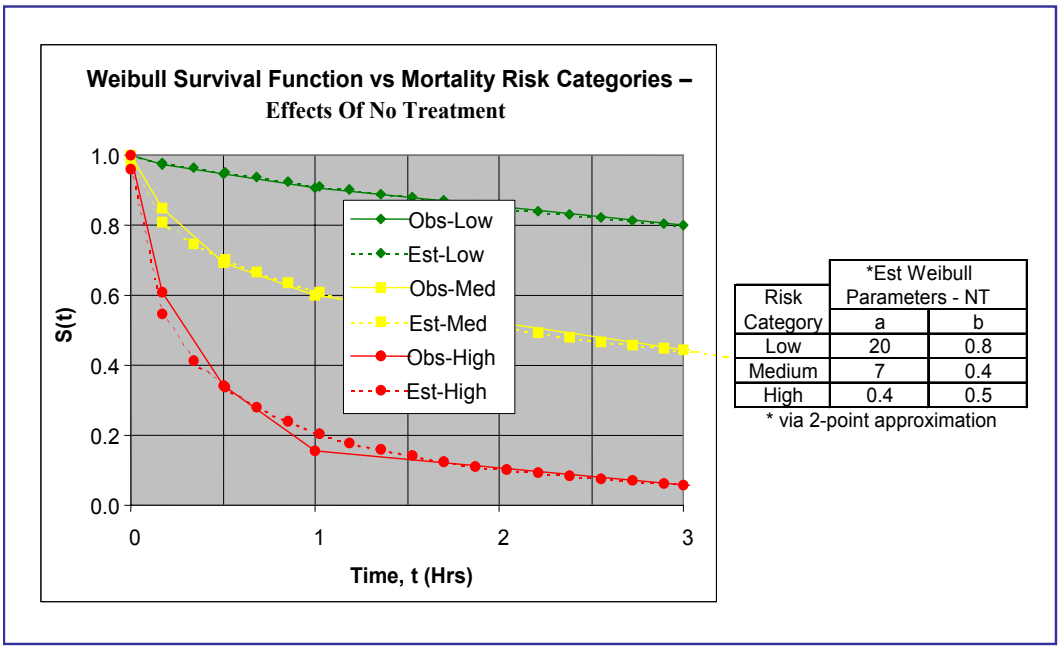
Folding SME results into a model such as TML+ can be handled in a variety of ways. Our original effort to describe a mortality function was to use least-squares regression analysis to curve-fit 1st Responder results at Camp Lejeune [7].

Another, more versatile, approach is to consider that the underlying stochastic process can be described by a probability density function for time to death, and then use the corresponding survival function (probability of survival past time "t") to simulate the mortality event.

It is this latter approach that we adopted from biomedical sciences literature. In this section, we describe how the Weibull survival function S(t) = exp[-(t/a)^b], with parameters "a" and "b", is used as our interim dynamic model in TML+ to simulate mortality of life-threatening injuries (see Figure 5).

In the context of simulating the died of wounds event across a set of MTFs representing an evacuation scenario, the variable "t" in S(t) will correspond to the time period as measured when the casualty enters an LOC alive. With reference to Figure 3, we seek to describe each curve with its own parameters "a" and "b" in the Weibull survival function S(t) where "t" is t1 for the 1st DOW check point shown, t2-t1 is the value of "t" in S(t) for the 2nd DOW check point and so forth.

For the initial implementation in TML+, which is primarily a placeholder until quantitative Navy-Marine Corps Combat Trauma Registry data are available for a statistical analysis, the parameters of the Weibull survival function S(t) are chosen such that the function matches the SME responses at two observations. Estimation of the parameters using all data points will be attempted by the method of least-squares or maximum likelihood on CTR results; other biomedical sciences death distribution models will also be examined.



Risk Category	*Est Weibull Parameters - NT	
	a	b
Low	20	0.8
Medium	7	0.4
High	0.4	0.5

* via 2-point approximation

Figure 14 - Weibull Survival Function applied to No Treatment results (by mortality category).

In Figure 14 we show the observed results for the three mortality risk categories and the fitted S(t) survival function values, as forced to match the SME responses at 0.5 and 3.0 hours after the time of injury. It is clear that the Weibull model describes the observed SME results very nicely; parameter estimates are also shown.

Figure 15 shows the 1st Responder SME results for the effects of no treatment for PC147 (the medium risk case) for treatment delays of 10 minutes, one hour, and three hours. We show this set of graphs to aid in helping decide if the Weibull parameters for a risk category and LOC might be dependent on the delay time in starting treatment at the particular LOC.

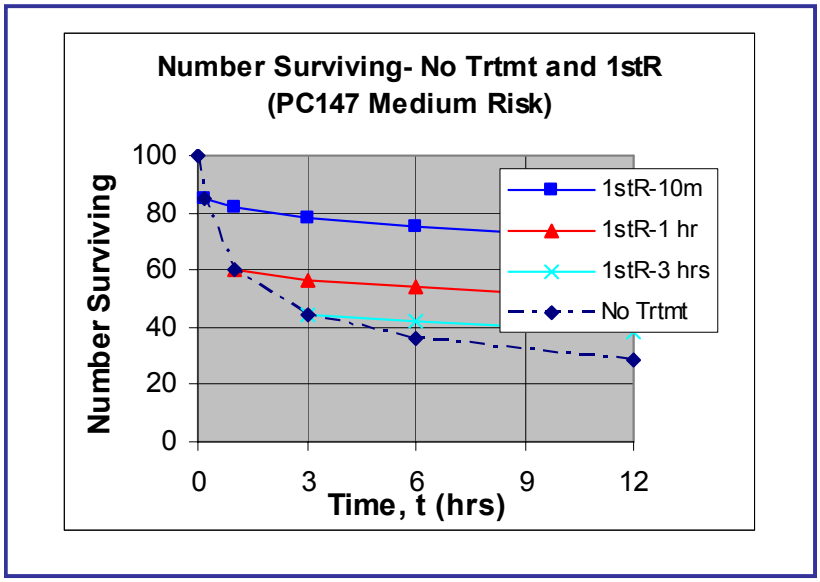


Figure 15 - Number Surviving for 1st Responder treatment with delays.

It is clear from the previous figure that the parameters of the Weibull survival function can be expected to vary by risk category but is there also an effect for the Weibull survival function for PC147, say, if the delay time in entering the 1st Responder is variable, as it undoubtedly will be in the queuing environment of TML+? To help answer this question for the initial implementation, Figure 15 allows us to examine the results for a set of timing delays and determine if they appear to have different shapes.

If they are judged to have different characteristics dependent upon time delay, then an interpolation scheme would have to be used to determine the applicable "a" and "b" values vs. time. The response grid that we solicited from the SME panel was designed with that possibility in mind.

Using the results in Figure 15 for PC147, we form the conditional survival function for each delay and plot them together on the left side of Figure 16, where the x-axis is now taken to be the time from entering the LOC (from 10 minutes, from one hour, etc). A quick visual inspection of these plots makes us doubt that there would be a serious need to consider that the parameters are dependent on treatment delay time. For the initial implementation we are willing to make this assumption; we do plan to revisit this idea when data become available from the Navy-Marine Corps Combat Trauma Registry.

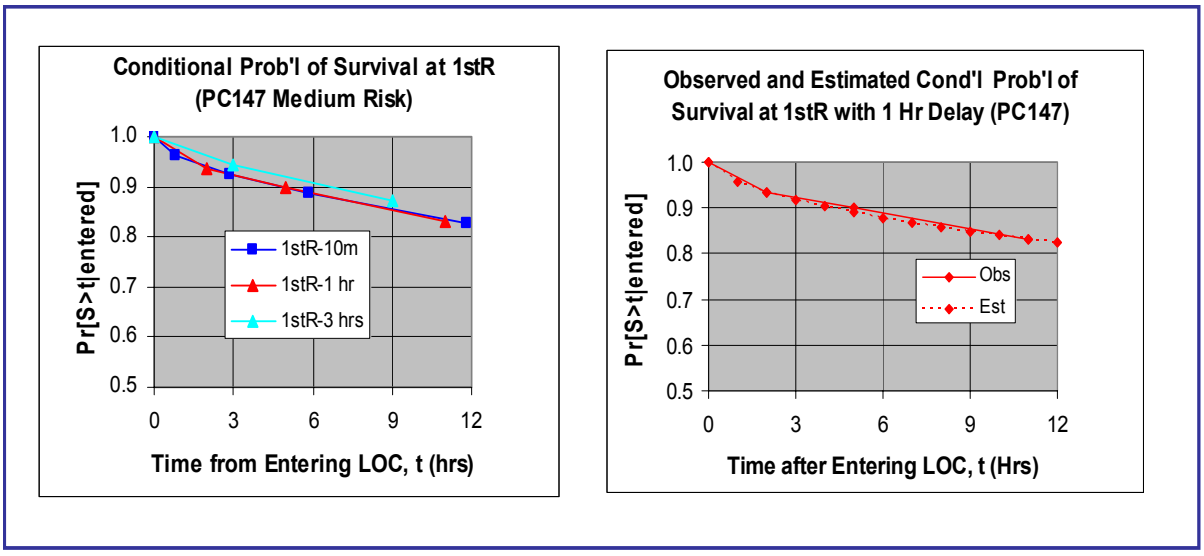


Figure 16 – Stability of Survival Function to 1st Responder treatment delays.

The right side of Figure 16 shows the fit of the Weibull survival function to the observed SME results for the delay of one hour, and again, we see a very nice agreement that is sufficient for an initial implementation. The estimates for the Weibull parameters for the 10 minute, 1 hour and 3 hour delay cases are (191, 0.6), (193, 0.6) and (145, 0.7), respectively, where each ordered pair gives a set (a, b).

Appendix C gives the Weibull parameters for the various evacuation routes. It is noted that we have appended the Weibull survival function by adding a multiplicative constant "c", such that the actual survival function used in TML+ is c*exp(-t/a)^b. For LOCs where the conditional survival function is approximately a constant (reference the latter LOCs in Figure 13), we set "c" to the constant value and make "a" and "b" large numbers so that S(t) is approximately equal to "c" for all time values. If the response is not constant, the above method of estimating the Weibull coefficients is used and "c" is set to 1.0.

Conclusions and Plans

In this paper we presented NHRC's research approach for using SME responses and empirical Navy-Marine Corps Combat Trauma Registry data to model the stochastic survival function for life-threatening injuries sustained on the battlefield when subjected to delays in the treatment stream across several interventions of medical care. We demonstrated the application of the widely accepted Weibull probability model from the biomedical sciences discipline to a set of medical provider SME opinions on the survival of a hypothetical set of 100 casualties with selected PCs as they progressed through several networks of MTFs. Three mortality risk categories were defined and it was shown how the Weibull survival model described the SME opinions for selected PCs in these categories. The fit was judged (qualitatively) to be reasonable for the initial implementation of a time-based mortality function in the TML+ planning tool.

It was noted that NHRC is collecting actual mortality and treatment data from all echelons of medical care in the Navy-Marine Corps Combat Trauma Registry and the descriptive results presented here will be re-examined with more inferential methods when a suitable sample of CTR data is available. The emerging technology called "pervasive computing" to obtain "anywhere, anytime, any data" is being investigated as a vehicle to automate medical source data collected in real time.

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Appendix A – Medical Provider Subject Matter Expert (SME) Panel

CAPT HR Bohman, MC, USN
CPS, 1st Medical Battalion, Naval Hospital Camp Pendleton

COL Sandra Brunken, RN (retired)
Joint Readiness Clinical Advisory Board

Howard Champion, FRCS, FACS
Tech Med, Inc. / SimQuest International, LLC

LT Chris Miller, MC, USNR
2d Battalion 2d Marines

CAPT John Perciballi, MC, USN
Naval Hospital Pensacola / OIC FRSS Team 4, Asst. CPS HSB

CMDR Peter Rhee, MC, USN
Navy Trauma Training Center

Ty Smith, MD
University of California, San Diego

LT CMDR Necia Williams, MC, USN
Naval Hospital Camp Lejeune

CAPT Jeffrey Young, MC, USN
Third Fleet

COL Kathleen Dunemn, AN, CNM, PhD
Center for AMEDD Strategic Studies

Appendix B – Mapping of Life-Threatening PCs to Risk Categories

PC	Patient Condition Description	HML for TML
5	Cerebral contusn closd intracranial hematoma w/without nondeprsd skull fracture-severe-rapidly deterioratg comatose	H
6	Cerebral contusn closd w/ nondprsd linear skull fract severe loss of conscious > 24 hrs w/w/out focal neurology. deficit	H
17	Wound face jaws & neck open lacer. w/ assoc. fractures excl. spinal fractures severe-w/airway obstruction	H
19	Wound face & neck open lacer. contused w/o fractures severe-w/airway obstructn and/or major vessel involvemt	H
27	Fracture spine closed w/ cord damage cervical spine w/ respiratory involvement	M
29	Fracture spine open w/ cord damage cervical spine w/ respiratory distress	M
45	Wound upper arm open penetrating lacerated without fracture severe – w/ nerve and/or vascular injury	L
47	Wound upper arm open w/ fractures & nerve and vascular injury arm nonsalvageable	H
53	Wound forearm open lacerated penetrating w/ fracture & w/ nerve and vascular injury forearm not salvageable	M
54	Wound forearm open lacerated penetrating w/ fracture & w/ nerve and vascular injury forearm salvageable	L
61	Crush injury upper extremity severe - limb not salvageable	L
62	Crush injury upper extremity moderate – limb salvageable	L
70	Amputation forearm traumatic complete all cases	M
71	Amputation full arm traumatic complete all cases	H
79	Burn thermal full thickness upper extremities > than 10% but < than 20% of total body area involved	L
87	Wound thorax (anterior / posterior) open penetrating w/ rib fractures, pneumohemothorax acute respiratory distress	H
94	Burn thermal full thickness trunk > than 20% but < than 30% of total body area involved	L
98	Wound liver closed acute (crush fracture) major liver damage	H
99	Wound liver closed acute (crush fracture) minor liver damage	L
100	Wound spleen closed acute (crush fracture) all cases	L
101	Wound abdominal cavity open w/ lacerating penetrating perforating wound to large bowel	L
102	Wound abdominal cavity open w/ lacer penetr perf wound of small bowel w/out major / multiple resections	L
103	Wound abdominal cavity open w/ penetrating perforating wound of liver major damage	H
104	Wound abdominal cavity open w/ penetrating perforating abdominal wound w/ lacerated liver	M
105	Wound abdominal cavity open w/ penetrating perforating wound of spleen	L
106	Wound abdominal cavity open w/ lacerated penetrated perforated wound w/ shattered kidney	H
107	Wound abdominal cavity open w/ lacer penetr perf wound w/ lacer. kidney repaired, subsequent nephrectomy	H
108	Wound penetration of pelvis w/ severe organ damage	M
109	Wound abdominal cavity open w/ lacerated penetrating perforating wound w/ lacerated bladder	L
114	Wound abdomen open w/pelvic fracture & penetrat perf wounds to multiple pelvic structures (male or female)	H
115	Wound abdomen open w/pelvic fracture & penetrating perforating wounds to pelvic colon only (male or female)	L
123	Wound thigh open lacerated penetrating perforating w/ fracture & nerve/vascular injury limb not salvageable	M
124	Wound thigh open lacerated penetrating perforating w/ fracture & nerve and/or vascular injury limb salvageable	H
130	Wound lower leg open lacerated penetrating perforating w/ fracture & nerve/vascular injury limb not salvageable	M
131	Wound lower leg open lacerated penetrating perforating w/ fracture & nerve and/or vascular injury limb salvageable	H
136	Wound ankle foot toes open penetrating perforating w/ fractures & nerve/vascular injury limb not salvageable	L
137	Wound ankle foot toes open penetrating perforating w/ fractures & nerve and/or vascular injury limb salvageable	L
138	Crush injury lower extremity limb not salvageable	M
139	Crush injury lower extremity limb salvageable	M
144	Amputation foot traumatic complete all cases	L
145	Amputation below knee traumatic complete all cases	L
146	Amputation traumatic complete requiring hip disarticulation	H
147	Amputation above knee traumatic complete	M
154	Burn thermal full thickness lower extremities & genitalia > than 30% but < than 40% of total body area involved	M
155	Burn thermal full thickness lower extremities & genitalia > than 15% but < than 30% of total body area involved	L
159	MIW brain & chest w/ sucking chest wound & pneumohemothorax	H
160	MIW brain & abdomen w/ penetrating perforating wound colon	M
161	MIW brain & abdomen w/ penetrating perforating wound kidney	M
162	MIW brain & abdomen w/ penetrating perforating wound bladder	M
163	MIW brain & abdomen w/ shock & penetrating perforating wound spleen	L
164	MIW brain & abdomen w/ shock & penetrating perforating wound liver	H
165	MIW brain & lower limbs requiring bilateral above knee amputations	M

PC	Patient Condition Description	HML for TML
166	MIW chest w/ pneumohemothorax & abdomen w/ penetrating wound colon	M
167	MIW chest w/ pneumohemothorax & abdomen w/ penetrating perforating wound kidney bladder	H
168	MIW chest w/ pneumohemothorax & abdomen w/ perforating wound bladder	L
169	MIW chest w/ pneumohemothorax & abdomen w/ penetrating perforating wound spleen	M
170	MIW chest w/ pneumohemothorax & abdomen w/ penetrating perforating wound liver	H
171	MIW chest w/ pneumohemothorax & limbs w/ fracture & vascular injury	H
172	MIW abdomen w/ penetrating perforating wound of colon & bladder	M
173	MIW abdomen w/ penetrating perforating wound of colon & spleen	M
174	MIW abdomen w/ penetrating perforating wound of colon & liver	H
175	MIW abdomen & limbs w/ penetrated perforated colon, open fracture & neurovascular injury of salvageable lower limb	H
176	MIW abdomen & pelvis w/ penetrating perforating wound of liver & kidney	H
177	MIW abdomen & pelvis w/ penetrating perforating wounds of spleen & bladder	H
178	MIW abdomen pelvis limbs w/ fracture & neurovascular injury limb salvageable & penetrating wound kidney	H
179	MIW abdomen pelvis limbs w/out fracture or neurovascular injury & penetrating perforating wound bladder	L
180	MIW abdomen & lower limbs w/fracture & nerve injury w/penetrtng wound spleen w/full thickness burns TBSA>20%	M
181	MIW abdomen & limbs w/out fracture or nerve injury w/ penetrating wound of liver	H
182	MIW chest w/ pneumohemothorax soft tissue injury to upper limbs & penetrating wound of brain	H
183	MIW chest w/ pneumohemothorax soft tissue injury to upper limbs & abdomen w/ wound of colon	M
184	MIW chest w/ pneumohemothorax pelvis & abdomen w/ wound of colon & bladder	M
185	MIW abdomen & chest w/ multiple organ damage	H
313	Wound abdominal cavity open w/ lacerated penetrating perforating wound kidney moderate - kidney salvageable	M

Appendix C – Weibull Coefficients for Initial Implementation

Weibull Survival Function Parameters for Life-Threatening PCs

S(t) = Pr(Survival > t) = c*exp (-(t/a)^b)),
where t measured from time casualty enters current LOC (ie, a survivor)
Notes:
1-Weibull parameters are {a,b}; the value "c" is included to allow a constant probability in certain LOCs where there is almost no variation in S(t)
2- Probability died-of-wounds in interval (0,t] = Pr(Survival <=t) = 1-S(t)

Route	Entering LOC	LOC & Mortality Risk Category	Parameters of S(t) a	b	c
POI to …	For DOW testing at LOC entrance after POI	Effects of No Trtmt			
		High	0.4	0.53	1
		Medium	4.6	0.47	1
		Low	18.7	0.82	1
1stR to …	For DOW testing at LOC entrance after 1st R	1st R Trtmt Effects			
		High	2.2	0.67	1
		Medium	126.5	0.71	1
		Low	22.6	0.98	1
1st R to BAS to …	For DOW testing at LOC entrance after BAS	BAS Trtmt Effects			
		High	7.0	0.57	1
		Medium	177.3	0.66	1
		Low	92.8	0.57	1
1st R to STP to …	For DOW testing at LOC entrance after STP	STP Trtmt Effects			
		High	396.0	0.42	1
		Medium	555.5	0.66	1
		Low	543.4	0.50	1
1st R to STP/FRSS to …	For DOW testing at LOC entrance after STP/FRSS	STP/FRSS Trtmt Effects-2			
		High	* 99999	9	0.97
		Medium	99999	9	0.97
		Low	99999	9	0.98
BAS to STP/FRSS to …	For DOW testing at LOC entrance after BAS-STP/FRSS	STP/FRSS Trtmt Effects-1			
		High	99999	9	0.85
		Medium	99999	9	0.98
		Low	99999	9	0.97

* - 99999 indicates <5% variation in SME estimated survival function over 1st 6 hrs (i.e., assume survival probability constant for this LOC and risk category)

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1. Report Date (DD MM YY)	2. Report Type	3. DATES COVERED (from - to)
08/10/04	Final	30 Sep 2003- Sep 2004

4. TITLE AND SUBTITLE
Modeling Dynamic Casualty Mortality Curves in the Tactical Medical Logistics (TML+) Planning Tool

5a. Contract Number:
5b. Grant Number:
5c. Program Element: 63706N
5d. Project Number: M0095
5e. Task Number: 005
5f. Work Unit Number: 60320

6. AUTHORS
Mitchell, Ray, Galarneau, Mike, Hancock, Bill, Lowe, Doug

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Health Research Center
P.O. Box 85122
San Diego, CA 92186-5122

9 PERFORMING ORGANIZATION REPORT NUMBER
Report Number 04-31

8. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Chief, Bureau of Medicine & Surgery
M2
2300 E Street, N.W.
Washington, DC 20372-5300

Marine Corps Systems Command
2006 Hawkins Avenue
Quantico, VA 22134-5010

10. Sponsor/Monitor's Acronyms(s)
BUMED/MARCORSYSCOM

11. Sponsor/Monitor's Report Number(s)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT (maximum 200 words)

Medical simulation models such as NHRC's Tactical Medical Logistics (TML+) planning tool stochastically represent the mortality of casualties with life-threatening injuries at various points in the Medical Treatment Facility (MTF) network flow. NHRC is seeking to determine a mathematical (probabilistic) representation of a conditional survival function that is reasonable in the context of other stochastic models being used in TML+. The paper describes NHRC's research approach to determine an acceptable TML+ model for the mortality function, describes SME opinion results being used as the basis for an interim descriptive model using a biomedical sciences probability model (Weibull), and gives the future plans to capture more quantitative mortality and treatment data from the Navy-Marine Corps Combat Trauma Registry and other sources to use in investigating the applicability of a full range of biomedical sciences probability models via inferential methods.

15. SUBJECT TERMS
Tactical Medical Logistics (TML+) tool, mortality curves, casualty modeling

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	b. THIS PAGE			Commanding Officer
UNCL	UNCL	UNCL		27	19b. TELEPHONE NUMBER (INCLUDING AREA CODE) (610) 553-8429

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18